AOARD-TR-94-05

AOARD REPORT

The 1994 IEEE Workshop on Micro-Electro-Mechanical Systems Oiso, Japan, 25-28 Jan 94

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The 7th International Workshop on Micro-Electro-Mechanical Systems, sponsored by the IEEE Robotics and Automation Society, was held 25-29 January 94 in Oiso, Japan . During this 3 day workshop, there were a total of 63 papers presented, consisting of 38 oral and 25 poster papers. Topics covered in this workshop were fabrication, sensor, actuator, device/system, and micro-robotics technologies of millimeter to micrometer-size electromechanical devices. One interesting paper presented in this workshop dealt with the fabrication of micro-actuators using magnetostrictive thin films. The basic idea of the paper was to create actuator motion by making use of magnetostrictive materials, consisting of amorphous Tb-Fe and Sm-Fe on a polymide film. It used the electromagnetic force, rather than more traditional electrostatic force. The paper reported the large deflection in cantilever actuator movement, implying the great potential for the future use of magnetostrictive actuation devices for achieving millimeter size actuator motion. As a whole, the workshop was organized well and there were very interesting papers presented in this workshop, resulting in invigorating discussions during the question and answer period.

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The 1994 IEEE Workshop on Micro-Electro-Mechanical Systems
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by

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Abstract

The 7th International Workshop on Micro-Electro-Mechanical Systems, sponsored by the IEEE Robotics and Automation Society, was held 25-29 January 94 in Oiso, Japan . During this 3 day workshop, there were a total of 63 papers presented, consisting of 38 oral and 25 poster papers. Topics covered in this workshop were fabrication, sensor, actuator, device/system, and micro-robotics technologies of millimeter to micrometer-size electromechanical devices. One interesting paper presented in this workshop dealt with the fabrication of micro-actuators using magnetostrictive thin films. The basic idea of the paper was to create actuator motion by making use of magnetostrictive materials, consisting of amorphous Tb-Fe and Sm-Fe on a polymide film. It used the electromagnetic force, rather than more traditional electrostatic force. The paper reported the large deflection in cantilever actuator movement, implying the great potential for the future use of magnetostrictive actuation devices for achieving millimeter size actuator motion. As a whole, the workshop was organized well and there were very interesting papers presented in this workshop, resulting in invigorating discussions during the question and answer period.

I. Introduction

The IEEE International Workshop on Micro-Electro-Mechanical Systems (MEMS) is one of the established international workshops dealing primary with designs, modeling, fabrication, operation, and application of electromechanical devices which are built to the size of micrometers. The workshop provides a forum for researchers from all over the world to get together once a year to discuss emerging technologies in the field of microelectromechanical systems. Since the first workshop was held in Hyannis, U.S. in 1988 , the workshop was held every year for the past six years in the U.S., Japan, and Germany, i.e., four in the U.S., one in Japan and one in Germany. This year's workshop was the seventh in the series and was held between 25-28 January 94 at Oiso (near Yokohama), Japan.

The workshop has attracted more than 400 participants world-wide with many of them coming from the host country, Japan. There were 63 papers presented, consisted of 3 invited, 35 oral, and 25 poster papers. There were 30 papers presented by Japanese researchers altogether, dominating the conference platform with almost a half of the total papers presented in this workshop. It showed a strong active research interest by Japanese in this field where the Japanese government has taken the initiative to start a well-organized program a few years ago to cultivate the microelectromechanical device technology in Japan. Many of those Japanese papers were presented jointly by Japanese companies and Japanese academic institutions, if not solely by Japanese companies,

indicating a strong research bond between Japanese companies and Japanese academia. It was especially the case for research in the "Devices and Systems" arena where four out of eight papers were in somewhat of the joint effort by Japanese companies and Japanese academia. On the other hand, most of the non-Japanese papers came from their countries' academic institutions.

The three invited talks covered the following topics: "Micromechanism and Their Characteristics" by Prof. T Hayashi, Toin University of Yokohama; "Materials for Lithography Galvanoformung Abformung (LIGA) Products" by Prof. W. Ehrfeld, IMM Institute Fur Mikrotechnik GmbH; and "Feyman Revisited" by Prof. S. D. Senturia, MIT.

The oral presentation was divided into 7 categories: Micro-Fluid Handing (4 papers), Modeling (2 papers), Sensors (1 paper), Actuators (7 papers), Fabrication Methods (9 papers), Devices and Systems (8 papers), and Micro Robotics (4 papers).

The poster session was divided into 9 categories: Materials (3 papers), Buckling (2 papers), Damping (2 papers), Fabrication (5 papers), Fluids (1 paper), Sensors (4 papers), Actuators and Micro Robotics (3 papers), and Teleoperation and Micro Assembly (5 papers).

II Discussions of Presented Papers

The following describes some important points discussed in invited talks and topical sessions.

II.a Invited Talks

Prof. Teru Hayashi provided the general outline of the growing Japanese interest in microelectromechanical systems. He started his talks with a historical view of the mechanical engineering field and discussed various types of modeling techniques used to analyze micromechanical systems. He pointed out that a micromechanical system can be uniquely divided into five general categories based on its system characteristics. Using his naming convention, he identified them as 1) size effect on forces, 2) strength increase in material, 3) strength of surface feature, 4) decrease of manufacturing accuracy, and 5) natural law of speed and principles of moving objectives.

In the second invited talk, Prof W. Ehrfeld and his co-workers discussed the LIGA process where the name was derived from the German name Liographie Galvanoformug Abformung. The LIGA process is actually based on a combination of deep lithography, microelectroforming, and micromoulding processes. It allows the generation of microstructures with extremely large aspect ratios and submicron tolerances for metals (including metal alloys), plastics, ceramics, and glasses. At present, a wide variety of microstructure products were developed using this process and are already out in market. The potential for applications of microstructure products is vast covering such fields as information and communication, chemical engineering, automation and robotics, optoelectronics, aerospace engineering, and medical science. Just to mention some products made from the LIGA process, there are microsensors, microactuators, fiber-optical connectors, optical couplers, components for endoscope and catheter systems, implant and drug release system, and microgears. Prof Ehrfeld discussed the characteristics of materials used in the LIGA process, starting with materials for deep

lithography, which is the first step in the LIGA process, then proceeding to materials for micro-electro-forming, and finally ending with materials for micromoulding.

In the third invited paper, Prof S. Senturia of MIT discussed the miniaturization of electromechanical devices from the view points expressed in 1959 and 1983 speeches by Professor Richard Feyman, California Institute of Technology. Prof Senturia called the talk "Feyman Revisited." As Prof Senturia mentioned in his talk at the beginning, the paper was prepared rather hastily with only a few weeks given to him by the workshop committee because the invitation came relatively late. Nevertheless, the talk was well prepared and conveyed the essence of miniaturization ideas that Prof Richard Feyman has conceived back in 1959. The talk was centered around two main ideas with one idea being "There's Plenty of Room at the Bottom" and the second as "Infinitesimal Machinery." Based on these ideas, Prof Senturia described concepts behind how Feyman decided to explore four major areas of miniaturization systems, namely, 1) information storage, 2) computers, 3) manipulation of atoms, and 4) machinery. In the summary, Prof Senturia had a lot of good things to say about Feyman as seen by the following synopsis taken out of Prof Senturia's conference manuscript: "Feyman was clearly a visionary. He also understood the laws of physics deeply, and he had remarkable imagination and curiosity. Thus, he could define directions and opportunities very far in advance of actual technological developments. We will always need intellectual vision to define our path, and Feyman's contributions in this arena se the highest possible standards."

II.b Topical Sessions

In the Micro-Fluid Handling session, a group of researchers headed by Prof. Koji Ikuta of Kyushu Institute of Technology, Japan, presented the successful demonstration of a new type of three dimensional micro-fabrication processes, called the "Integrated Harden Polymer Process." The work was based on the use of micro-stereo lithography and electro-plating techniques. The basic idea of the processing is to start with setting up the polymer structure which in turn is used to cast the metal into the polymer structure by electroplating. Finally the polymer is removed by solvent or the appropriate chemical process to obtain the final three dimensional metal structure. It is the use of the polymer that is new in this process as compared with a more traditional Silicon process which is based on anisotropical etching and surface micro machining. The paper also went into discuss the hybrid process where both the Silicon process and the Integrated Hardening Polymer process were used to improve the processing characteristics, especially, of three dimensional micro integrated fluid systems.

In the Modeling session, there were two papers presented. One paper was by J.G. Korvink which dealt with the recent advance made in modeling of an integrated microelectromechanical system using the framework of the existing code called SESES. The code was developed by Korvink in 1993. The SESES code is a quasi-steady state code and it provides flexible coupling of electrical, thermal, and mechanical deformation phenomena. It uses the automatic mesh adaptation algorithm for solving 2 and 3 dimensional problems to the mesh size of up to 100,000 mesh elements using standard and hybrid finite element methods. Now the code can be run in workstations and simulates complex three dimensional geometry problems with excellent computational accuracy. To date, the code can simulate many coupled micro-machine devices which combine electrostatic and elstostatic effects. The second paper, given by MIT

researchers, dealt with self-consistent simulation modeling of electrostatic deformed diaphragms. The paper discussed three different levels of modeling used for simulations, namely 1) a very simple lumped parallel-plate-capacitor-plus-spring model, 2) a one-dimensional numerical model based on beam and/or plate theory with loads derived from an incrementally parallel-plate capacitor, and 3) fully self-consistent three dimensional numerical simulation combining finite element structural modeling with multipole-accelerated boundary element capacitance analysis. The relative merits of each model are described in detail with specific examples, revealing the limitation of the two simplified modeling methods. It concluded that for simple structures with small deflections, the simplified modeling can simulate with far less computational burden, where as when it comes to simulating complex structures such as non-parallel conductors, the 3-dimensional model is needed to properly handle large deflections.

In the area of actuators, there were couple interesting papers presented which dealt with fabrications of actuators using electromagnetic force. In one paper, T. Honda of Tohoku University proposed the use of magnetostrictive materials for microactuators which are driven by electromagnetic force in order to achieve the large deflection in cantilever actuator motion. The paper showed that when the thin film is fabricated with Amorphous-Tb-Fe or Sm-Fe, cantilever actuators exhibited the large deflection under low magnetic fields, indicating the evidence of achieving large enough electromagnetic force which may increase the future consideration of using the electromagnetic force for micro-machine applications.

Another paper which dealt with magnetic actuators was presented by researchers from California Institute of Technology, headed by Chang Liu. They presented the successful fabrication of surface micromachined micro-magnetic actuators which are capable of achieving large deflections on the order of 100 micrometers with an applied magnetic force of approximately 1 micro-Newton at a resonant frequency of 1 KHz. The actuator was designed for as an integral part of an active microelectromechanical fluid system. Although there was a significant amount of thermal deflection observed, which turned out to be comparable to that of the magnetic deflection, C. Liu and his associates believe that the thermal problem can be solved by simply reducing the resistance of the coil path, which in turn results in reducing heat generation.

In the session dealing with Fabrication Methods, there was a paper which described a new type of the metal line patterning process based on use of a KrF excimer (ultraviolet) laser, instead of a visible Argon laser, to induce the selective non-planer metallization or deposition of chromium film from gas phase precursors. The paper was presented by S. Maeda of Tohoku University. According to the paper, the use of the KrF excimer laser resulted in achieving high resolution laser induced chemical vapor deposition with significantly less surface damage as compared with the visible Argon laser. One possible application of this new process is in the fabrication of a tectile sensor at the end of a smart catheter for micro surgery devices which are used in medical applications. The tectile sensor can measure the force applied at the end of the catheter and help to prevent any injury of the inner wall of the blood vessel. Basically the structure of the tectile sensor was created by making use of chromium as an etching mask for patterning the underlying nickel film, which it self was deposited first on polymer surface prior to depositing chromium.

The second interesting paper in Fabrication Method session was presented by Prof K. Ikuta of Kyushu Institute of Technology, Japan. He reported the first successful demonstration of depositing TiNi thin films on substrate using the laser ablation method. The laser ablation method makes use of an excimer laser to ablate TiNi molecules off the bulk TiNi target and then deposit them onto substrate to form a thin film. He pointed out that the laser ablation method has superior characteristics than vacuum vapor deposition and sputtering methods when it comes to controlling Ti-Ni composition and contamination.

In the Devices and Systems session, there were two interesting papers presented by Japanese researchers. One paper, which entitled "Design and Fabrication of Miniature Relay Matrix and Investigation of Electromechanical Interference in Multi-Actuator Systems", dealt with the successful development of a miniaturized 8x8 matrix relay switch. The switch is built to dimensions of 28x32x7 mm, which is about one tenth by volume of the conventional relay switches available in market. The paper was submitted by H. Hosoka and H. Kuwano of Nippon Telegraph and Telephone Corp (NTT). It seems almost certain that with this new relay switch available we would expect to see even smaller integrated relay systems sold in market very soon.

The second paper was interesting because it discussed the development of an integrated optical micro-encoder chip where their findings can be extended into making other kinds of optical sensors and components. The paper was submitted by R. Sawada, O. Ohguchi, K. Mise, and M. Tsubamoto of NTT. The paper reported the successful development of an advanced integrated optical microencoder, the device that's capable of measuring relative displacement and traveling direction of grating scale with respect to the microencoder itself. The relative displacement is measured with accuracy on the order of 0.01 micrometers. If the encoder is combined with silicon-on-insulator technology, then it is possible to come up with more intelligent integrated optical sensors, possibly one-chip sensors which include microprocessors and driving circuits.

III. Microelectromechanical Research Programs in Japan

In Japan, the basic idea of creating miniaturized electro-mechanical devices has been discussed for a long time; however, it is only in the last 5 years that both semiconductor and robotics technologies have advanced to the point where it is possible to build micrometer-size devices. The progress of microelectromechanical technology is tied very closely to the advance made in semiconductor and robotics fields. Nowadays, with growing interests in micro-machine medical surgery and miniaturized measuring instruments used for satellites, microelectromechanical technology became a separate field by itself to study the development of miniaturized electro-mechanical devices. In order to create micrometer size devices, it is very important to investigate the characteristics of the micro-environment where these devices need to operate and function properly to serve its need. Beside semiconductor and robotics fields, another important field that became an essential part of microelectromechanical technology is material science. Thus, the future of microelectromechanical technology can be said to depend on the progress of semiconductor, robotics, and materials research.

Having established the technological lead in semiconductor, robotics, and material science in last decade, Japan has started a very active program in Fiscal year 1991 to pursue the development of micro-machines under the sponsorship of the Ministry of International

Trade and Industry (MITI) as part of a 10 year National Research & Development Project entitled "Micromachine Technology." The responsibility of running the day to day operation of the program has been given to the MITI's Agency for Industrial Science and Technology (AIST). Functions of the AIST are to disseminate the information to proper working groups and to manage the Micromachine Center, which was established for the purpose of coordinating all Japanese microelectromechanical research activities. Recently, the center finished a study to identify specific areas of research that require additional attention to insure further progress in microelectromechanical technology. The study identified the following four areas: 1) Mechanism Technology, 2) Advanced Materials, 3) Design Features, and 4) Control Technology. Described below are some important aspects of research activities that need to be addressed in each area.

In the area of Mechanism Technology, it is important to understand a) the tribology in the mesoscopic area for practical and reliable applications of micro-machine devices and b) mechanisms associated with the interaction of environment and dynamic motion of micro-machine devices.

In the area of Advanced Materials, there are needs a) to perform theoretical and experimental investigation to understand characteristics of various actuator materials that are suitable for miniaturization, b) to investigate materials that are suitable for micro surgery, and c) to investigate the interaction of blood cells or soft tissues with micro-machine materials for the purpose of finding new materials that possess no adverse effect on blood cells or soft tissues.

In the area of Design Features, it is important to perform scale-effect and environmental impact analyses to insure the operational integrity of micro-machine devices in an environment that is different from the testing environment of the test device due to the fact that the test device is built larger than the actual device for the ease of testing. The analogy of using the test device to characterize the performance of the actual micro-machine device is the reverse of designing aircraft where a small model plane is tested in wind tunnel to characterize the performance of the actual size aircraft based on data taken for the small model plane.

And finally, in the area of Control Technology, a study is required to understand complex interactions of software and hardware for control of key micro-machine device components.

Having defined definite areas of research activities and with great importance placed by the Japanese government to take the lead in microelectromechanical research, Japanese industry and academia have taken an initiative to make a great leap forward to explore the frontier of microelectromechanical technology. I expect more quality research work would come out of Japan in the near future and Japanese scientists will be presenting new findings in international conferences and workshops around the world.